X-Ray Timing with Constellation-X

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Outline

Review of selected XTE results

Comparison of XTE and Con-X

X-ray timing science for Con-X

Inputs to Con-X mission requirements

XTE Timing Results

kHz quasiperiodic oscillations from BHC and NS
  → precision probe of accretion in strong gravity

X-ray burst oscillations
  → constraints on neutron star mass, radius

Millisecond X-ray pulsar
  → relativistic orbital evolution

Long-term monitoring of AGN
  → potential constraints on mass of central object

Anomalous X-ray pulsars
  → discovery of glitches similar to young radio pulsars

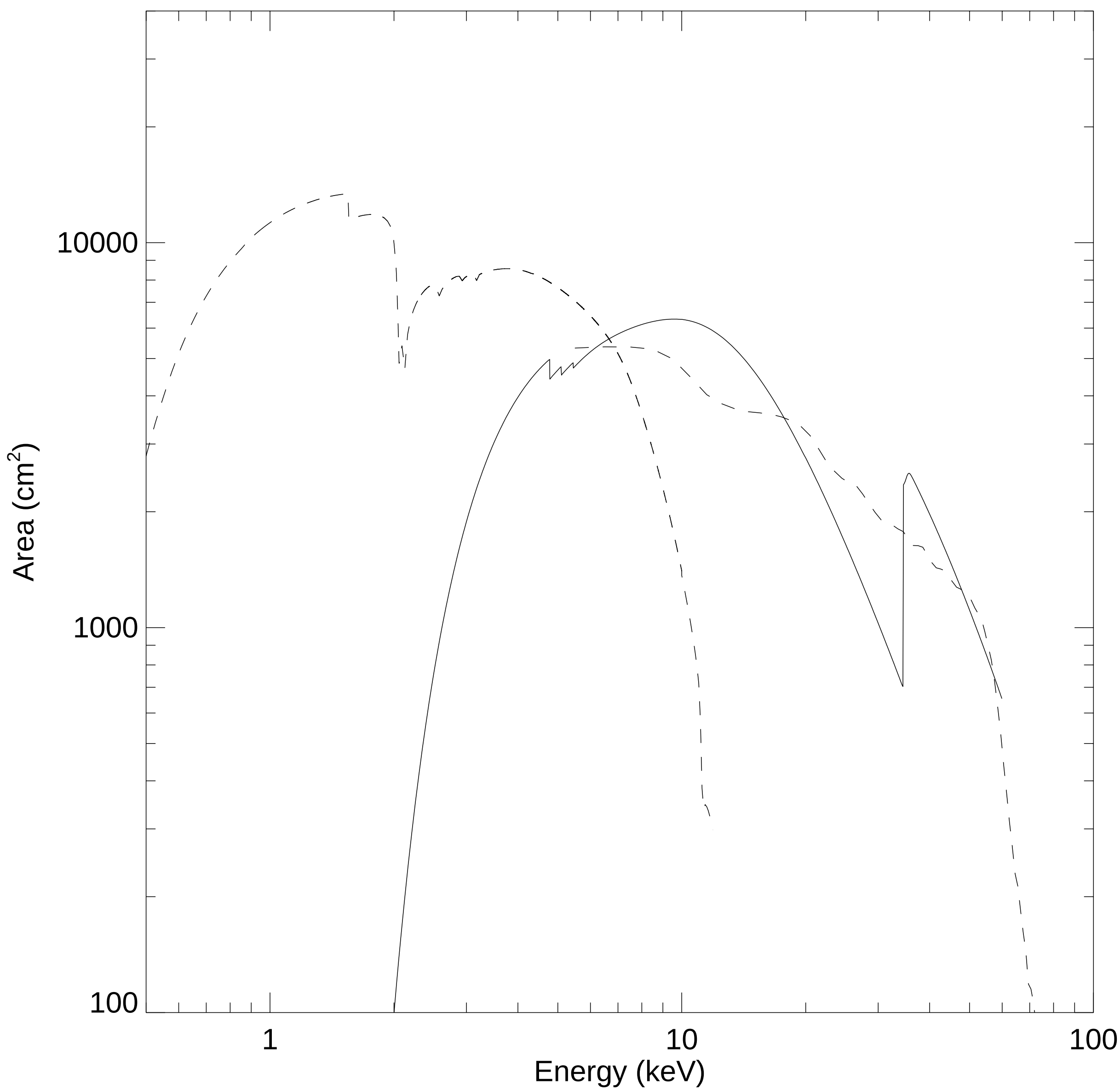
Mission capabilities

Millisecond time scales – high count rates

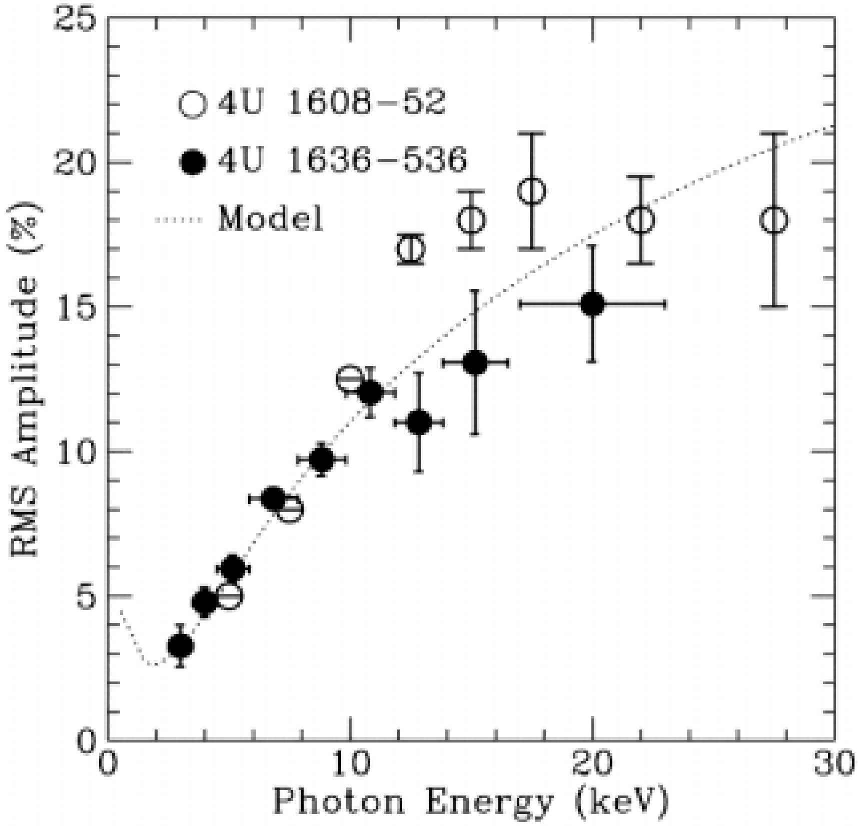
Long-term monitoring – repeated visits

Quick response to transients – flexible scheduling

Effective Area for Constellation-X versus RXTE/PCA

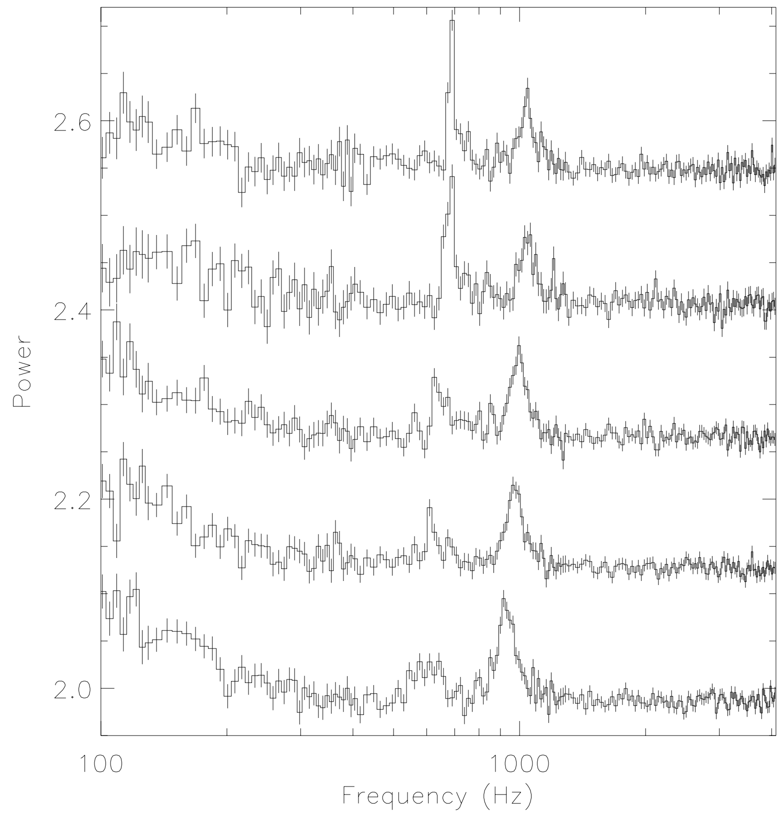


RMS Amplitude versus Energy



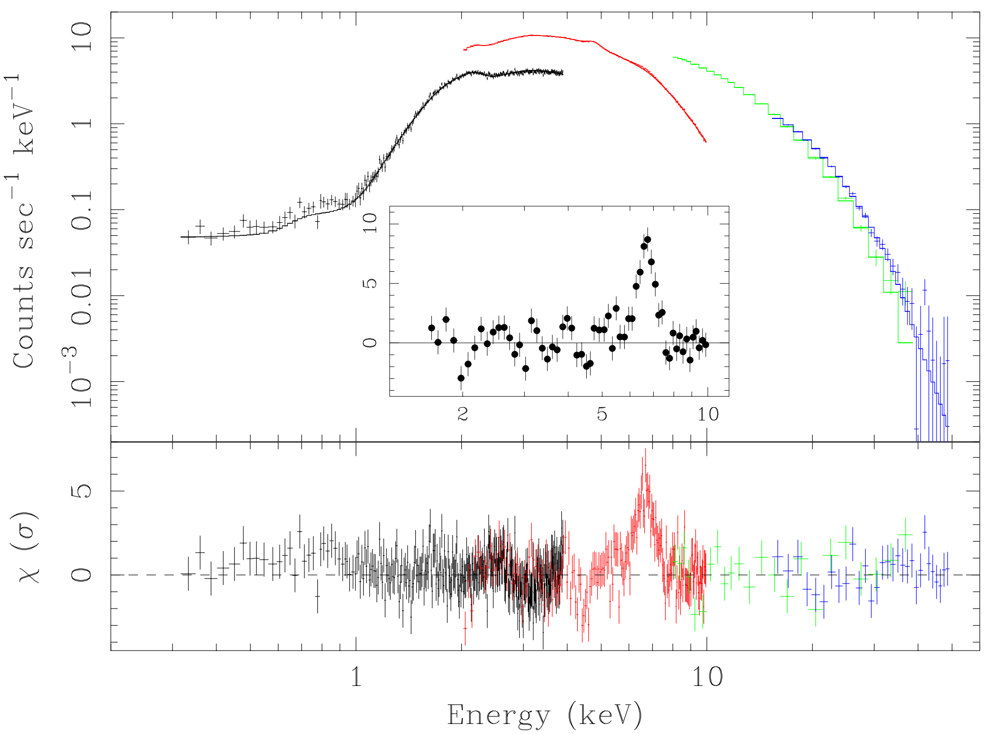
From Miller, Lamb, & Psaltis (1998)

Millisecond Oscillations



The dynamical time scale at the inner edge of an accretion disk, $r = 6GM/c^2$, surrounding a stellar mass object is in the millisecond range. The kHz QPOs discovered with RXTE probe this region of strong gravitational fields in both NS and BHC systems. The phenomenology of the QPOs has been interpreted as evidence for the existence of the marginally stable orbit and for Lense-Thirring precession, both key and untested predictions of general relativity.

Millisecond Oscillations

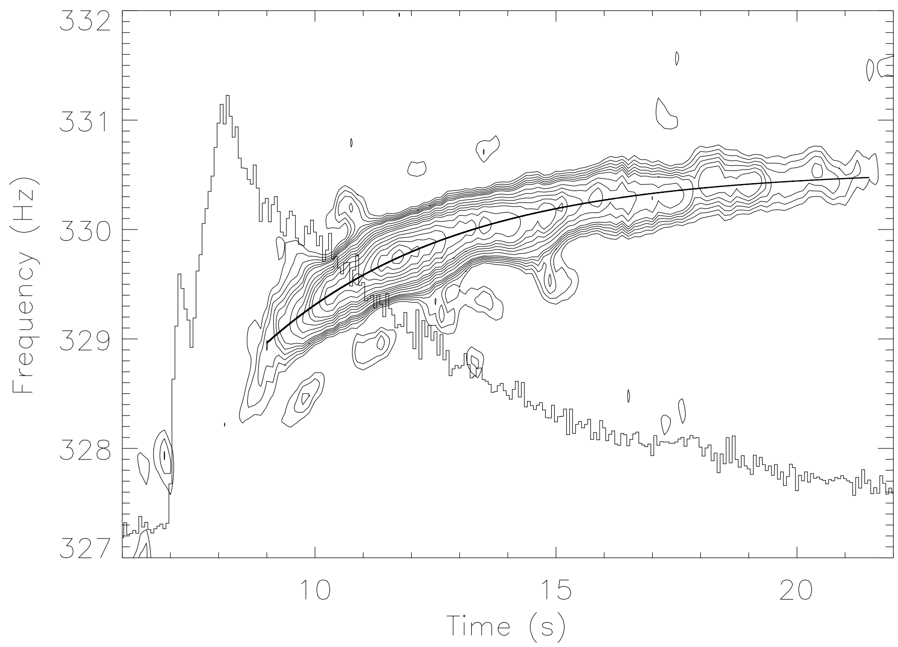


• Simultaneous measurement of a kHz QPO and either an Fe-line profile or the radius of a disk blackbody will test the interpretation of the kHz QPO as an orbital frequency via Kepler's 3$^{\rm rd}$ law, $\nu \propto r^{-3/2}$, and may permit measurement of compact object masses, $GM = 4\pi^2 r^3 \nu^2$.

• Con-X will extend kHz QPO to lower energies than possible with RXTE. This may be important in constraining QPO models.

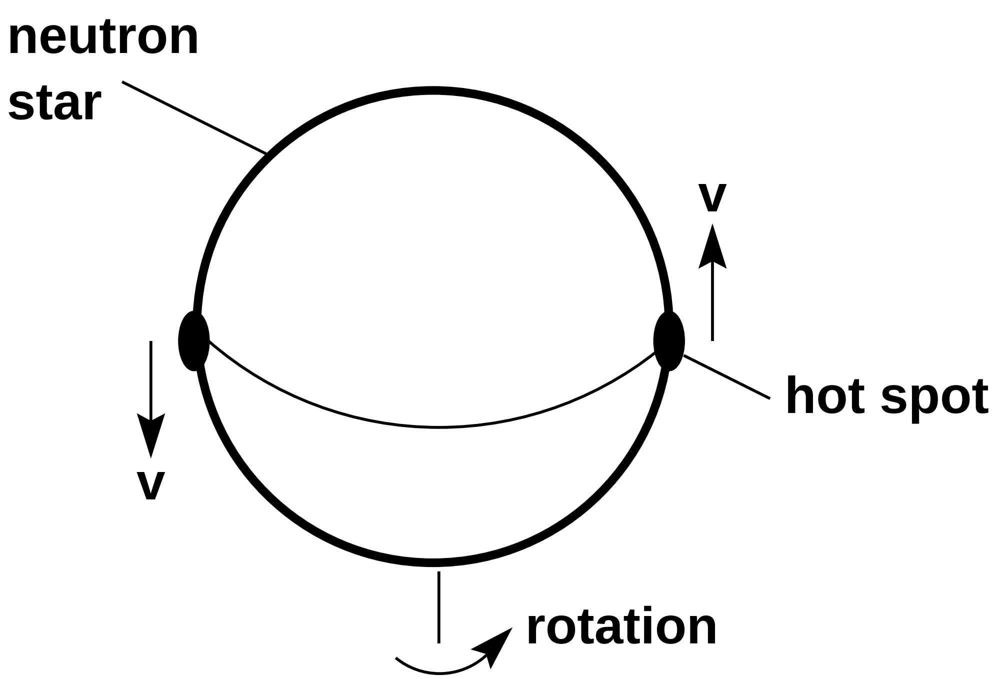
• Con-X will allow kHz QPO studies of dimmer sources than possible with RXTE, expanding the sample of sources, and potentially finding sources which stress current models.

X-Ray Burst Oscillations



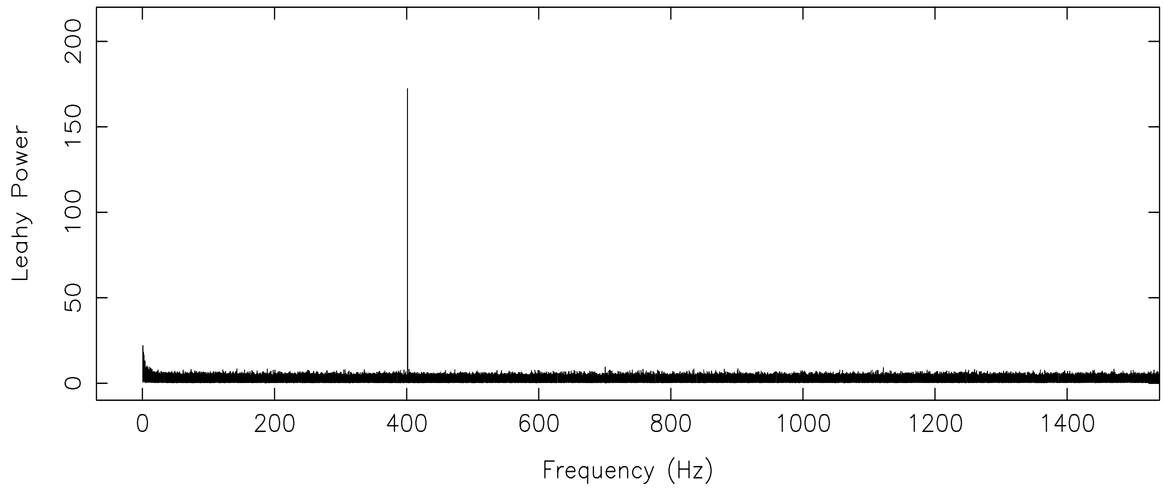
Oscillations at 250–400 Hz have been observed in x-ray bursts. In some cases, the oscillations are highly coherent $\nu/\Delta\nu \sim 4000$. The oscillations are interpreted as due to inhomogeneous nuclear burning on the neutron star surface.

X-Ray Burst Oscillations



• Using the burst oscillations, it should be possible to measure Doppler shifts of the emitted radiation and, thus, determine the velocity of the neutron star surface. Combined with the spin period, also measured from the bursts, this leads to a constraint on the neutron star mass-radius relation.

Millisecond X-ray Pulsars

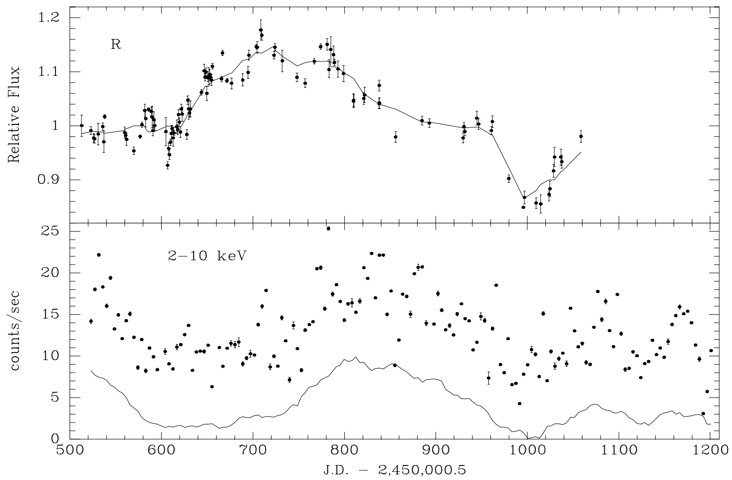


Coherent millisecond x-ray pulsations, at the level seen from SAX J1808.4-3, will be easily detected with Con-X. Con-X will also permit searches for much dimmer millisecond x-ray pulsars.

• Study of the x-ray pulse profile should lead to constraints on the mass and radius of the neutron star.

• Study of millisecond x-ray pulsars may allow measurement of relativistic orbital effects.

Monitoring Campaigns



Frequent monitoring of NGC 3516 led to the possible detection of a cutoff in the power spectrum and also of a correlation between the optical and x-ray emission.

• Short observations with a single Con-X spacecraft would be sufficient for monitoring and could lead to constraints on black hole masses and information about accretion disk dynamics in AGN.

Similar monitoring campaigns have been important in much other science conducted with XTE.

• Con-X could continue these advances, permitting us to determine the nature of anomalous x-ray pulsars, advance our understanding of accretion torques in x-ray binaries, constrain models of dwarf nova outbursts, and better understand the disk-jet interface and the relation of x-ray and radio emission from BH.

Timing Observations with Constellation-X

Instruments

Microcalorimeter (MC) 0.5–10 keV

Gratings/CCD 0.25–2 keV

Hard X-ray Telescope (HXT) 6–40 keV

Rate from Crab

MC: 80 kc/s (0.5–10 keV), 9 kc/s (4–10 keV)

HXT: 7 kc/s (6–40 keV)

XTE/PCA: 10 kc/s (2-25 keV), 7 kc/s (4-25 keV)

Rate limit

MC: 40 kc/s

HXT: needs to be specified

- For a bright x-ray source with a count rate near the rate limit, a typical observation of 50 ks will require 200 Gbit of on-board storage. At a telemetry rate of 1.7 Mbps, 33 hours of ground contact will be required to telemeter the data.

Observing Galactic Black Hole Transients

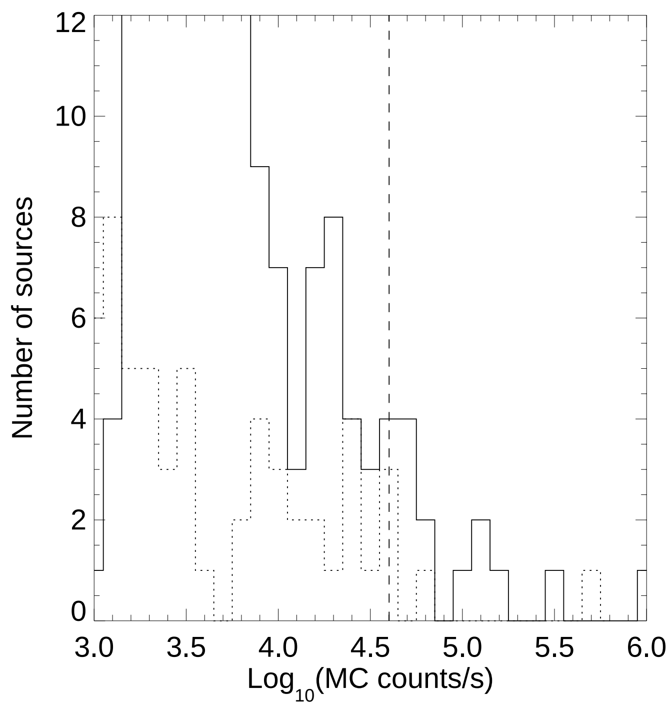
From the Decadal Survey description: "Constellation-X is the premier instrument to probe the formation and evolution of black holes, both stellar black holes in our Galaxy..."

- To observe Galactic BHC during their bright phases, Con-X must capable of handling high count rates.

MC count rates for peak fluxes of some BHC transients

XTE J1550-546	290 kc/s
Nova Sco 1994	140 kc/s
GRS 1915+105	120 kc/s
V4641 Sgr	96 kc/s
Cyg X-1	62 kc/s
GRO J1744-28	56 kc/s
XTE J1859+226	50 kc/s

Inputs to Constellation-X Mission Parameters



• Millisecond timing requires the capability to observe bright sources. The count rate for 4U 1728-34, a typical bright x-ray burster, is 3×10^4 c/s in MC, 1×10^4 c/s in MC above 4 keV, 7×10^3 c/s in HXT. Bursts give peak MC rates of $10^4 - 10^5$ c/s.

To observe brighter sources or for longer observations:

1) Commandable lower energy threshold for microcalorimeter
2) Movable filter ($\sim 50\mu$m Be with 2% holes)
3) On-board processing to reduce data storage

Inputs to Constellation-X Mission Parameters

- Accreting sources are highly variable and exhibit a range of source states. TOO response within 12 hours would help maximize the scientific return and within 24 hours would be acceptable in most cases.

- Absolute timing accuracy of $\pm 50\mu s$ is adequate to study QPOs up to 2000 Hz and to search for sub-millisecond pulsars.

- Long-term monitoring (for AGN, anomalous x-ray pulsars, dwarf novae, disk-jet interaction via x-ray/radio correlations, etc.) requires repeated visits. In many cases, a single Con-X spacecraft would suffice.